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DOCUMENT-IDENTIFIER: US 5945768 A
TITLE: Piezoelectric drive circuit

ABPL:
A piezoelectric motor drive circuit is provided which utilizes the piezoelectric elements as oscillators and a Meacham half-bridge approach to develop feedback from the motor ground circuit to produce a signal to drive amplifiers to power the motor. The circuit automatically compensates for shifts in harmonic frequency of the piezoelectric elements due to pressure and temperature changes.

BSPR:
The present invention generally relates to piezoelectric motors and similar devices. More specifically, the present invention relates to a unique electrical circuit to drive traveling wave piezoelectric motors and related piezoelectric devices.

BSPR:
Devices such as piezoelectric traveling wave motors, which will be referred to herein simply as piezoelectric motors, are devices which utilize deformation of small piezoelectric elements to provide motive force. The elements used in such devices are piezoelectric ceramics or crystals which deform when exposed to an electric field. By exposing a set of piezoelectric elements to a series of timed electrical pulses, a motion can be derived from the elements. Piezoelectric motors are increasingly found in common uses in today's society, such as in drives to operate lenses on automatic cameras, drives to operate curtains and shades, and a variety of other uses requiring small lightweight, inexpensive, and reliable motors.

BSPR:
Piezoelectric vibration devices, such as piezoelectric motors and actuators use an oscillating voltage electrical source to cause the piezoelectric elements to vibrate. In particular, traveling wave piezoelectric motors depend upon generation of two standing waves displaced both a quarter wavelength in time and in space to form a traveling wave in the motor stator. This is typically accomplished by feeding a sine wave and a cosine wave (i.e., a sine wave and a sine wave displaced a quarter wavelength in time) to elements displaced a quarter wavelength spatially around the stator. General motor circuit and timing considerations are discussed in the application of Charles Mentesana, U.S. application Ser. No. 08/628,141, filed Apr. 4, 1996 ("Mentesana") which is incorporated herein by reference. (Both Mentesana and the present application are assigned to a common entity.) In order to most effectively induce the

traveling wave, piezoelectric motor drive circuits are designed to produce these standing and traveling waves at or near frequencies at which the motor is resonant.

BSPR:
One characteristic of piezoelectric motors is that the resonant frequency of the motor changes in accordance with the temperature and pressure experienced by various portions of the motor, and especially the piezoelectric elements. Changes in ambient temperature, heating of the motor elements due to friction, electrical resistance, and the like cause significant temperature shifts in the motor. Similarly, in operation, the motor rotor is in contact with the motor stator, the pressure of which contact varies in operation due to various factors including temperature changes and motor wear. As a result of these pressure and temperature changes, significant changes in motor operating frequency result during motor operation. It is noted that the resonant frequency is also dependent upon motor torque, motor configuration, and similar factors. However, the primary variable operational factors are pressure and temperature. For simplicity, references herein to temperature and pressure factors affecting the harmonic frequency, include such other factors.

BSPR:
One approach to driving these piezoelectric motors has been to generate electrical pulses with set frequencies to drive the motor. This approach limits the operating range and efficiency of the motor because the selected frequency generally is a compromise between the range of harmonic frequencies anticipated in motor operation.

BSPR:
It is, therefore, an object of this invention to provide a circuit design for driving piezoelectric motors which inherently compensates for frequency mode changes due to changes in temperature, pressure, and like factors.

BSPR:
The present invention is directed to a circuit to drive piezoelectric motor devices that satisfies the needs to enhance motor drive circuit reliability, simplify manufacturing, and, thus, reduce cost. The circuit basically is a half Meacham bridge crystal oscillator circuit in which the piezoelectric device is utilized as a crystal oscillator to establish the basic frequency mode of the circuit by balancing the ground side of the piezoelectric motor elements.

DEPR:
Because the piezoelectric elements of a piezoelectric motor are ceramics which behave like crystals, the piezoelectric elements function as a crystal oscillator in the circuit to self-generate a signal at the harmonic frequency of the piezoelectric element. The present invention utilizes a unique combined ground-side electrical feed from the piezoelectric elements to derive the appropriate phase-separated waves in order to automatically derive the harmonic frequency of the

individual piezoelectric elements. This configuration forms a Meacham half-bridge circuit. In some embodiments, an impedance element is utilized in the ground circuit to create a back-voltage signal, which voltage signal is the superimposed combined current of the piezoelectric motor ground currents. In other embodiments, the piezoelectric element is coupled through a transformer to isolate the piezoelectric element and allow production of a back voltage feedback signal. This back voltage is utilized as a signal feed to drive phase shifting and amplification circuits which, in turn, drive the motor elements.

DEPR:
One preferred embodiment of the present invention is generally depicted in FIG. 1. In this embodiment, motor elements, shown as E11 and E12, are connected through transformers T11 and T12 to phase-shifting amplifiers A11, A12, A13, with the signal modified by resistor R11 and parallel capacitor C11. A reference point V11 is also identified. The circuit is an oscillator design based upon a Meacham half-bridge concept which uses the piezoelectric motor element E11 as the frequency sensitive element to sustain oscillation and therefore adapts the drive signal to changes in the resonant frequency of the motor due to pressure and temperature variations. Reference herein to a Meacham half-bridge circuit includes the balance bridge concepts incorporated in the following embodiments.

DEPR:
The operation of the embodiment shown in FIG. 1 is advantageously explained by reference to FIGS. 2 and 3. In FIG. 3, capacitors Cd and Cm along with inductor Lm and resistor Ro represent an equivalent circuit for a piezoelectric element, denoted by the phantom line as E31. The equivalent components Cm and Lm are commonly referred to as motional capacitance and inductance, respectively and represent electrical characteristics of a piezoelectric element which vary with temperature and pressure. Equivalent component Cd is typically referred to a shunt capacitance and equivalent component Ro is referred to as series resistance; both are generally invariant under temperature and pressure changes, as compared to the harmonic considerations resulting from components Cm and Lm. For general reference, in a typical piezoelectric element commonly used in piezoelectric motors, Lm is on the order of 1 Henry (H), Cm is typically 4-7 Pico Farads (pF), Ro is on the order of 20-200 Ohms, Cd is on the order of 1,000 to 30,000 pF.

DEPR:
The purpose of the circuit shown in FIG. 3, a Meacham half-bridge circuit, is to produce a null signal at the test point shown as Vo at a harmonic frequency of the piezoelectric element E31. Because the value of parallel capacitance Cd is much greater than Cm, the harmonic frequency response primarily is controlled by components Lm and Cm. A null signal at Vo is advantageously accomplished by applying sine wave signals which are 180.degree. out of phase with the equivalent piezoelectric element E31 on one side of Vo and to a parallel resistor Rs and

capacitor Cs on the other side of Vo. If the resistor Rs and capacitor Cs are sized to have approximately the same value as the series resistance, Ro and shunt capacitance Cd, respectively, of the piezoelectric element E31, it readily may be seen that the effect of components Ro and Cd at point Vo may effectively be canceled, leaving the effect of components Lm and Cm. Because the values of components Lm and Cm are much more temperature and pressure dependent than those of components Cd and Ro; changes to the resonant frequency of the element E31 due to pressure and temperature are due to the contribution of components Lm and Cm. The impedance of components Lm, Ro, Cm may be given by:

DEPR:
In this embodiment, the reference point, V41, balancing resistor R41, and capacitor C41, are moved to the other side of the transformer T41 as compared to the embodiment shown in FIG. 1. If transformer T41 is a center tap ground unit, the effective potential to ground experienced by R41 and C41 is 180.degree. out of phase as compared to that expressed by element E41 and has a comparative absolute value related to the number of windings in the respective portions of the transformer, shown as N2 and N3. One result of the use of a center tap transformer is that a 180 degree phase shift amplifier is not required in this embodiment. Further, as the number of turns N3 is reduced as compared to N2, the resistance of resistor R41 correspondingly may be reduced and C41 increased while maintaining a balance at the summing point, V41. This, in turn, reduces overall loop impedance for the components, the piezoelectric element E41, transformer T41, and resistor/capacitor R41/C41, which results in increased efficiency of power conversion.

DEPR:
In typical traveling wave piezoelectric motors, the common or ground side of all of the piezoelectric elements is interconnected. Thus, ground current flow is a combination of superimposed current flows from the elements. As noted above, in order to provide a true .+-.180.degree. phase shift at a summing point, either isolation transformers are utilized as in the foregoing embodiments, or an elevated common voltage amplification system is required. The embodiment shown in FIG. 6 demonstrates an embodiment of the present invention in which isolation transformers are eliminated, but at some reduction in circuit stability. The embodiment shown in FIG. 6 consists of piezoelectric elements E61 and E62, which are interconnected at a common point, the summing point V61, and isolated from ground by impedance device Z61. Amplifiers A61 and A62 are interconnected to the feedback provided by means of a system of resistors, R61 to R68, and capacitors, C61 and 62, to produce the appropriate 0.degree. and 90.degree. phase shift required on the outputs of amplifiers A61 and A62.

DEPR:
In this embodiment, the ground current flow taken through an impedance device, Z61, produces a voltage equivalent to a product of the superposition of the combined currents from

elements E61 and E62 taken through the impedance. Since these currents are required to be a sine wave and a sine wave displaced 90.degree., the resulting waveform at node V61 is a sine wave phase-shifted 45.degree., or one-eighth wavelength in time. If the voltage signal thus produced is provided to appropriate phase-shifting amplifiers, A61 and A62, through a phase-shifting network, such as components R67, R68, C61 and C62, the appropriate sine and cosine waves result for driving the piezoelectric elements. In this configuration, resistors R61 through R66 are used to control the respective gains of the amplifiers, and R67 and R68 along with C61 and C62 are used to set the phase shift. The required phase shift of the feedback signal at the input of amplifiers A61 and A62 is .+-.45.degree. in order to produce the required 0.degree. and 90.degree. phase shifts on the output of amplifiers A61 and A62.

CLPR:
1. A drive circuit for a vibration wave piezoelectric motor including piezoelectric elements having a harmonic frequency and interconnected at a common point, comprising:

CLPR:
2. A drive circuit for a vibration wave piezoelectric motor as claimed in claim 1 in which said feedback circuit means is a Meacham half bridge circuit.

CLPR:
3. A drive circuit for a vibration wave piezoelectric motor as claimed in claim 1 in which said feedback circuit means includes a filter for selecting preferred frequencies of feedback signals.

CLPR:
4. A drive circuit for a vibration wave piezoelectric motor as claimed in claim 1 further comprising means for inductively balancing said oscillator circuit so as to improve drive circuit power factor.

CLPV:
oscillator circuit means for producing an electrical signal for driving the piezoelectric elements of the piezoelectric motor in which said oscillator circuit means is self-oscillating and said piezoelectric elements form a portion of said oscillator circuit means;

CLPV:
a traveling wave piezoelectric motor, which motor utilizes a first plurality of piezoelectric elements and a second plurality of piezoelectric elements, each said element with an input and an output, said element outputs being electrically interconnected;

CLPV:
a traveling wave piezoelectric motor, which includes a first plurality of piezoelectric elements and a second plurality of piezoelectric elements, each said element with an input and an output, said element outputs being electrically interconnected,

said elements having fixed impedance portions, the electrical characteristics of which are essentially invariant over changes in pressure and temperature;

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USPT,PGPB,JPAB,EPAB,DWPI,TDBD	phase adj1 shift$ same 180 same degree$ and (piezo$ or ultrasonic or vibration adj1 wave adj1 motor)	294	L4
USPT,PGPB,JPAB,EPAB,DWPI,TDBD	phase adj1 shift$ same degrees same inver$ and (piezo$ or ultrasonic or vibration adj1 wave adj1 motor)	47	L3
USPT,PGPB,JPAB,EPAB,DWPI,TDBD	phase adj1 shift$ same degrees and (piezo$ or ultrasonic or vibration adj1 wave adj1 motor)	1139	L2
TDBD	phase adj1 shift$ same degrees	133	L1

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